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BOUNDARY DISTURBANCES NEAR AN UNDERWATER EXPLOSION BUBBLE

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BOUNDARY DISTURBANCES NEAR AN UNDERWATER EXPLOSION BUBBLE

by

William G. Zuke

ABSTRACT: High speed photographs of a number of underwater explosions of 0.2 gram lead azide charges were made. For moderately deep explosions (where the charge depth is one to two maximum bubble radii), water jets above the surface and tubes of air extending down from the surface appeared at points where cables penetrated the surface. Similar phenomena were observed when cables were not present; however, the magnitudes were generally smaller. The occurrence of these phenomena is qualitatively related to Taylor's Instability Theory.

If the characteristics of the model explosions of this study are presumed to scale geometrically full-scale nuclear explosions, it can be tentatively concluded that: For moderately deep explosions, atmospheric air flows into the tubes and toward the explosion bubble, and the most likely effect is somewhat increased mixing of radioactive products with the water.

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UNDERWATER EXPLOSIONS DIVISION
EXPLOSIONS RESEARCH DEPARTMENT
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The work reported here is an initial laboratory investigation of a phenomenon which may be of importance in interpreting radiological and surface phenomena of large scale explosions. While the results of this study are strictly applicable only to tiny explosions, it must be inferred that the effects observed may be present on explosions of large chemical or nuclear weapons.

The work done here was carried out under Task No. RE01-ZA732/212-9/F008-21-003.

R. E. ODENING
Captain, USN
Commander

C. J. Aronson

C. J. ARONSON
By direction

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The author is deeply indebted to the efforts of the late Graden L. Barker who carried out the initial study reported here.

The author is also indebted to Dr. E. Swift, Jr. for reviewing the text and for his many useful comments and suggestions.

BOUNDARY DISTURBANCES NEAR AN UNDERWATER EXPLOSION BUBBLE

1. INTRODUCTION

In field studies of underwater explosions, the charge is usually suspended by a cable from the water surface. Other cables may be used to suspend instruments nearby. It has been tacitly assumed that these cables had only a negligible effect on the gross explosion phenomena.

Recent concern about the transport mechanism of radioactive materials in a nuclear explosion bubble to the surface has resulted in a re-examination of this assumption. It was speculated that cables extending from the explosion bubble to the surface might provide a path for early venting and release of radioactive products.

To investigate this possibility, a few small scale experiments were carried out in the NOL vacuum tank in 1959. High speed photographs were taken of tiny charges with and without cables from the surface. This limited program, summarized in Section 2, showed that there were effects both above and below the surface which were ascribable to the presence of the cables.

In an attempt to define the conditions under which these effects might occur and be of importance in full scale explosions, further tests under controlled conditions were carried out. These tests are described in Sections 3 and 4 of this report.

The effects which were observed are qualitatively related to Taylor's Instability Theory in Section 5. The application of Taylor's Instability Theory suggests that effects similar to those observed at the air-water boundary may occur at the explosion bubble-water boundary.

2. PREVIOUS STUDY

Laboratory scale underwater explosion studies at NOL have been conducted in a vacuum tank. References (a), (d), and (g) present descriptions of this facility and the nature of studies conducted in it. The major variables at the experimenter's disposal are the charge weight, charge depth, water depth, and air pressure. In the initial cable effects study these variables were fixed. The charges were standard MK 113, Mod 1 primers containing 0.115 grams of a diazodinitrophenol and potassium perchlorate mixture. The charges were placed on a one-inch thick rubber mat on a steel plate 5.0 inches beneath the surface. The air pressure above the water was at 10 inches of mercury absolute.

The variables in this study were concerned with the properties of the cable. Cable placement was the same in all cases: two cables were vertically suspended, one over the charge and extending down to it, and the other about three inches off center and extending to about mid-depth. Cable materials were varied to provide a range of roughness, flexibility, and size. These materials were:

(1) Stranded wire, AWG No. 22-7/30, 0.025 inch diamter,

(2) Beaded light pull chain, 0.093 inch diamter,

(3) Solid copper wire, AWG No. 16, 0.050 inch diamter.

In addition, some shots were fired without cable as controls.

Selected frames from the sequence of photographs taken with an Eastman High Speed camera at about 2800 pictures per second are shown in Figures 1 through 4. Figure 1 shows a control shot. In it, we note that the surface development (general growth of the water mound) exhibits a relatively smooth surface until about the time the bubble is at its maximum. This feature is slightly different from that observed with cables present and is markedly different from that observed in large explosions.

In large explosions the spray dome is evident on the surface from very early times, starting from the time when the shock wave has impinged upon it. It appears as a frothy layer of multitudinous droplets and it obscures the solid water mound beneath it. In very small scale shots, the spray dome does not appear at all or merely exhibits a few spindly fine spikes of water over the water mound which is clearly in view. Thus, until about the time of the bubble maximum, the surface of the water mound appears relatively smooth as in Figure 1.

One apparent effect of the cable is the generation of jets of water upward from the water mound. In Figures 2 and 3 these jets are seen at the cable over the explosion. When the original film strips were viewed in motion, a smaller jet is also apparent at the second cable, three inches to the side. It is questionable whether these jets would be seen on large shots, since they might be masked by the spray dome.

A second characteristic due to the cables is noted at later times under water. In the control shot (Figure 1), at late times when the bubble is contracting, some projections appear beneath the water dome. There were none on a second control shot. On the shots with cables (Figures 2, 3, and 4), these projections are very apparent in the vicinity of the cables. They are larger and penetrate downward more deeply than in the control shot. In most cases these projections made contact with the explosion bubble and in a few cases, broke away from the surface to unite with the bubble.

At the time of the initial studies these projections were thought to be regions of dense cavitation. As a result of the current study these projections are now believed to be tubes of atmospheric air penetrating downward. Similar observations have been reported in References (c) and (e).

It was concluded in the initial study that cables suspended in the vicinity of an underwater explosion give rise to jets above the surface and cavitation below. In order to corroborate this conclusion and to determine the effects of variables not previously considered, another experimental program was conducted. The following sections are concerned with that program.

3. PLAN OF EXPERIMENT

In expanding on the previous study it was felt desirable to consider the effects of explosion geometry, air pressure and cable distance from the center of the explosion. At the time of experimental planning this author was not aware of any theoretical mechanism to explain cable influence on the generation of jets or air tubes. Thus, the variables introduced were based primarily on intuition and convenience.

It was felt that the position of the bubble relative to the surface would have an effect on the magnitude of jets and air tubes produced since these phenomena seemed to result from the interaction of the bubble with the surface. Three scaled charge depths were arbitrarily selected, thus providing three explosion geometries. In the geometric scaling employed here, all dimensions are reduced by the maximum bubble radius, A_{max}, thus geometrically scaled charge depth is defined as d/A_{max}. Values of d/A_{max} were 1.0, 1.5, and 2.0.

Since the air tubes were at first thought to be cavitation, it was felt that air pressure might also be a significant variable. At reduced pressures it was expected that cavitation would be more marked than at atmospheric pressure. Three air pressures, P, were arbitrarily selected. These were 34 feet of fresh water (one atmosphere), 10, and 3 feet of fresh water.

Cables were positioned over the charge, and 3 and 6 inches to the side, since the initial study indicated a reduction in the amplitude of jets and tubes at positions away from the centerline of the explosion. The cable lengths were the same as the charge depths. Geometrically scaled cable distances were compared

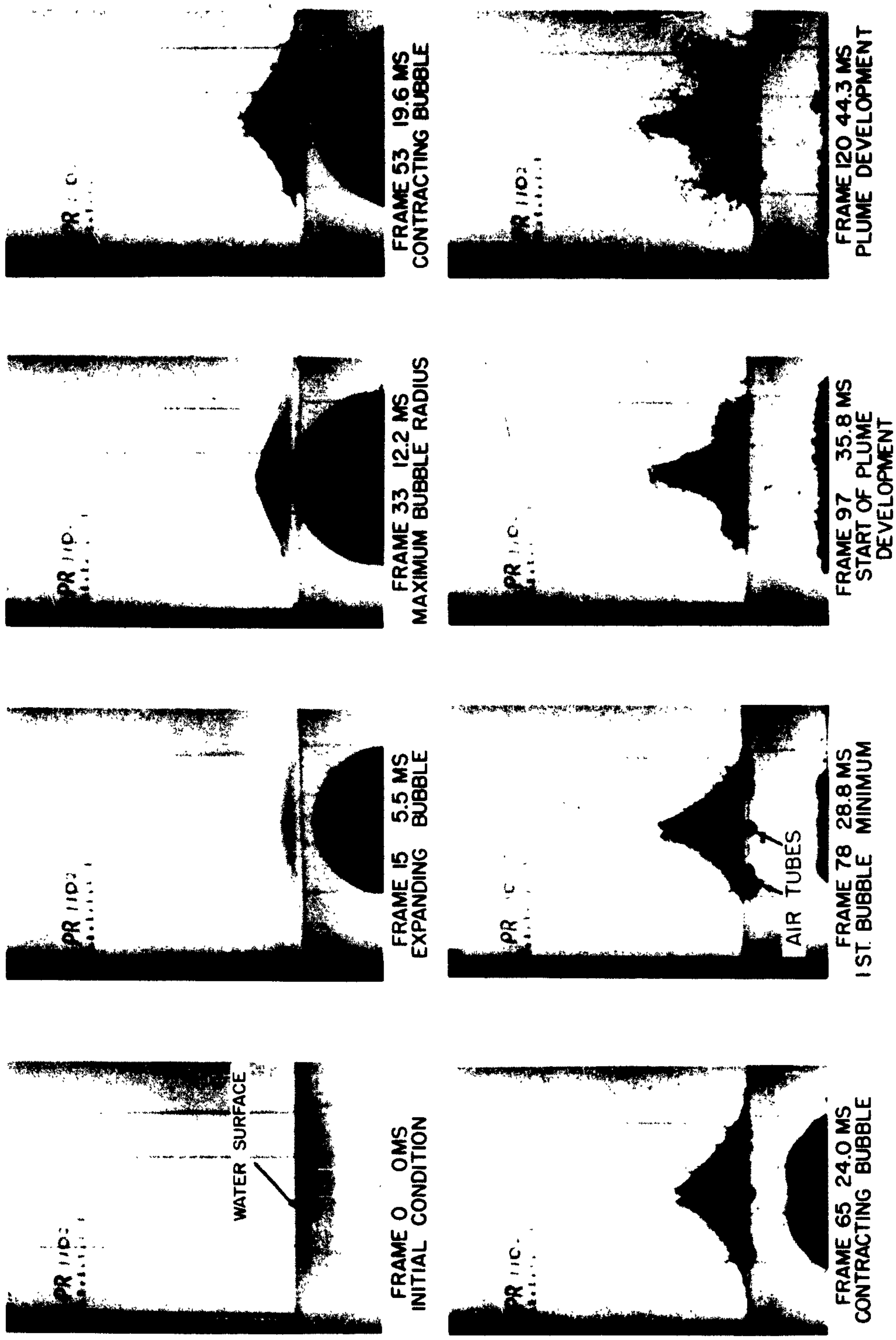


FIG.1 PICTURES OF SHOT NUMBER PR 1102 (CONTROL SHOT)

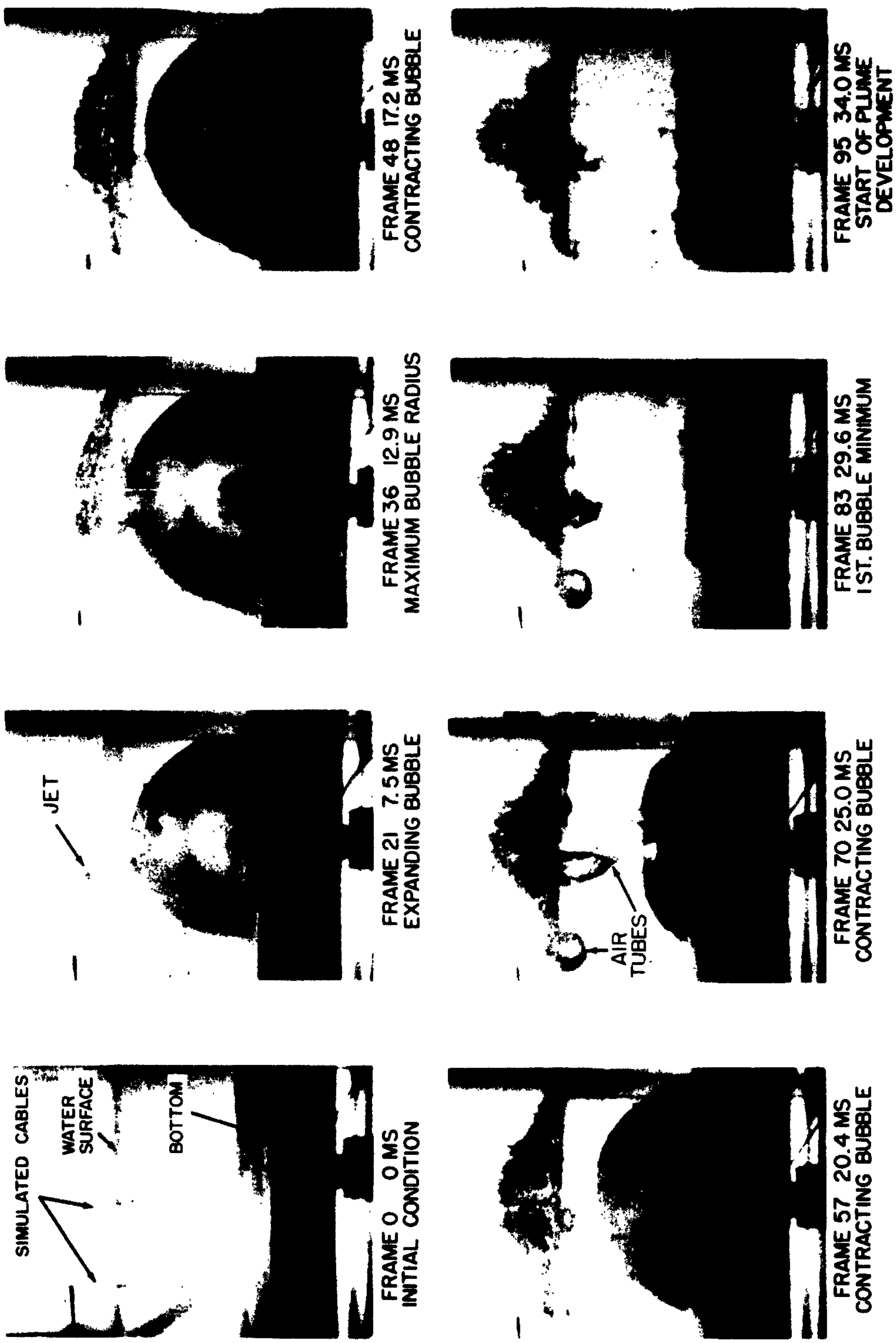


FIG.2 PICTURES OF SHOT NUMBER PR 1108 (SOLID WIRE)

FRAME 0 0 MS
INITIAL CONDITION

FRAME 6 4.8 MS
EXPANDING BUBBLE

FRAME 21 17.0 MS
MAXIMUM BUBBLE RADIUS

FRAME 26 21.0 MS
CONTRACTING BUBBLE

FRAME 30 24.0 MS
CONTRACTING BUBBLE

FRAME 34 27.4 MS
CONTRACTING BUBBLE

FIG. 3 PICTURES OF SHOT NUMBER PR 1109 (CHAIN)

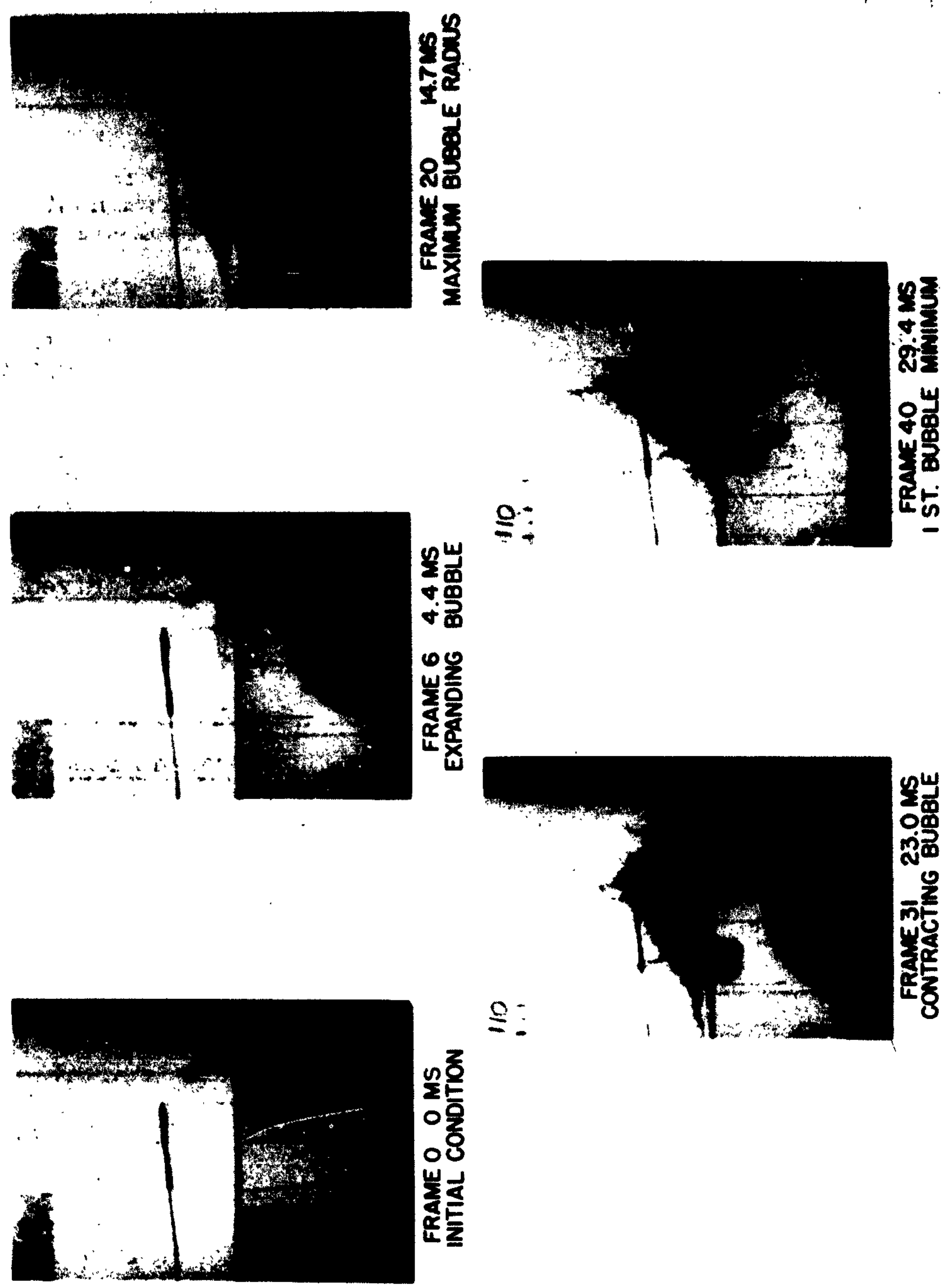


FIG.4 PICTURES OF SHOT NUMBER PR 1110 (STRANDED WIRE)

to evaluate the effect of cable position. Scaled cable distances from the explosion centerline are here defined as S_i/A_{max} where S is the distance from the centerline, i = 1, 2, 3, and refers to cable 1 over the centerline, cable 2 at 3 inches off center and cable 3 at 6 inches off center.

Since the initial study indicated that all three cable materials used produced jets and tubes, it was felt that this variable was not significant. The cable material used throughout this study was solid copper wire, AWG 12, 0.081 inches in diameter.

The charge weight was held constant as in the initial study; however, a different charge was used. This charge was 0.2 grams of lead azide and was selected because its explosion characteristics were available. These data were used to determine the firing depths required, and their application is discussed below.

Another difference from the initial experiments was that in the current experiments all shots are in deep water where bottom effects are assumed negligible. This condition was required since the explosion data available are for deep water.

The experimental conditions of the two studies are summarized in Table 1.

TABLE 1. EXPERIMENTAL CONDITIONS

	Initial Study	Present Study
Scaled Charge Depth, d/A_{max}	Approximately 1.0	1.0, 1.5, 2.0
Air Pressure, P	10" Hg(11'H_2O)	34'H_2O,10'H_2O, 3'H_2O
Cable Position from Centerline	0, Approx. 3"	0, 3", 6"
Cable Material	3 Types	Solid Wire
Charge	MK 113, Mod 1	0.2 gm lead azide
Bottom	Shots on bottom	No bottom

Having arbitrarily selected values of the scaled depth, d/A_{max}, and air pressure, P, it was necessary to determine what the actual charge depth, d, should be. Use was made of data reported in Reference (h) to give Figure 5 which shows a family of curves relating the maximum bubble radius with air pressure for three charge depths when a special 0.2 gram lead azide charge (Reference j) is used and when the water is at approximately 48°F. Figure 6, derived from Figure 5, relates scaled depth to air pressure for

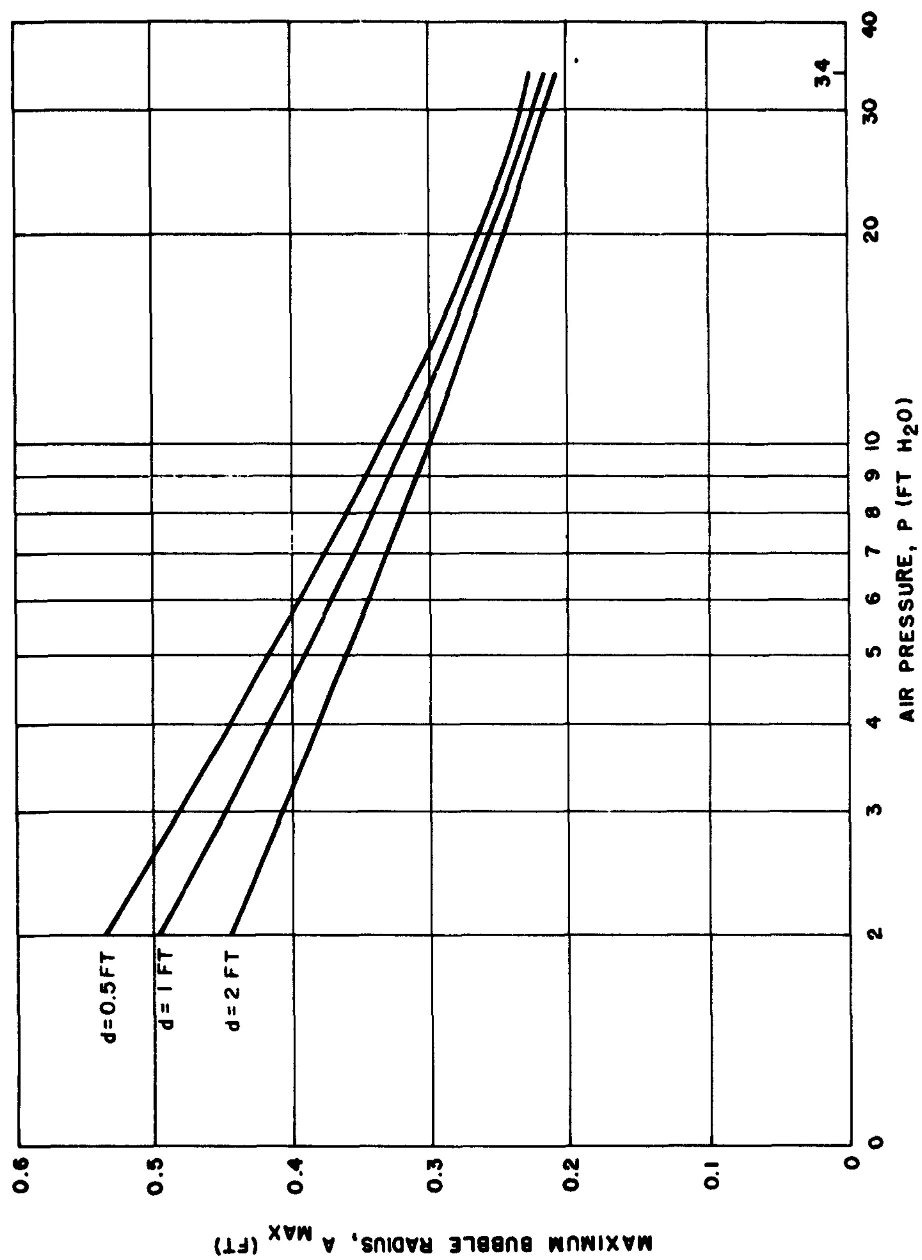


FIG 5 MAXIMUM BUBBLE RADIUS VS AIR PRESSURE FOR VARIOUS CHARGE DEPTHS

(FOR 0.2 GRAM LEAD AZIDE CHARGES IN WATER AT 48° F)

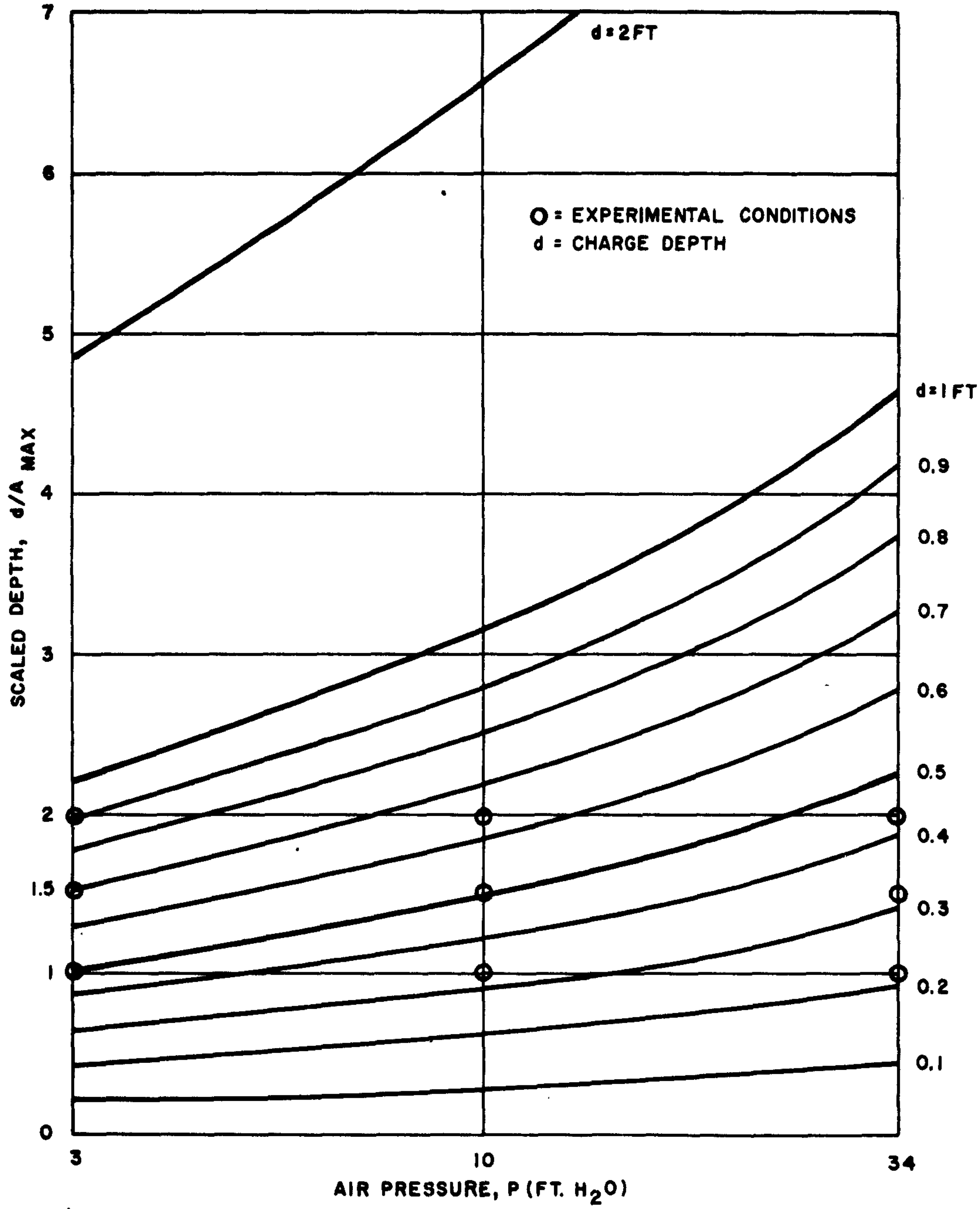


FIG 6 SCALED DEPTH VS AIR PRESSURE FOR VARIOUS CHARGE DEPTHS

(FOR 0.2 GRAM LEAD AZIDE CHARGES IN WATER AT 48°F) various charge depths. The nine experimental conditions for the scaled depths and air pressures are indicated. The charge depths are interpolated from the family of depth curves.

One shot (with cables) was fired at each of the nine experimental conditions. Five control shots (without cables) were fired; one shot at five of the experimental conditions. One additional shot was later added to the program to obtain a closer observation of the tubes. The experimental program is shown in Table 2.

4. RESULTS

Several frames have been selected from the high speed photographs of six shots and are presented in Figures 7 through 12. These show the explosion at various stages: (a) the charge position and mounting just prior to initiation, (b) shock cavitation (also called bulk cavitation) which results from the shock wave reflection from the water-air boundary, (c) the expanding bubble and bulging water mound at the surface, (d) the bubble at its maximum size, (e) the contracting bubble, (f) the bubble at its first minimum, and (g) the re-expanding bubble.

Figures 7 and 8 are the control and experimental shots at a scaled depth of 2.0 and with an air pressure of 3 feet of water; Figures 9 and 10 are at a scaled depth of 1.5 and an air pressure of 10 feet of water; Figures 11 and 12 are at a scaled depth of 1.0 and an air pressure of 34 feet of water.

A jet appears at most cables; however, photographic resolution is very poor. In most photographs its presence can be detected only by its base or neck around the cable. It sometimes appears as a growing hollow cylindrical sheath of water about the cable. Its vertical extent is virtually impossible to determine. For this reason measurements of jets were not made.

The deepest air tube penetrations usually occurred at the cables. They were generally at their maximum extent just before or at the time of the bubble minimum. It was decided to make all penetration measurements at similar times - the time of the bubble minimum was used. Measurements of the maximum penetration, C_m, were made as well as extent of penetration at each cable, C_i (where $i = 1, 2$ or 3). All values were reduced by dividing by A_{max}.

In Figure 13, tracings of the profiles of all the shots of this experiment are presented. These show the original position of the charge and water surface, the bubble at its maximum and the corresponding surface effects at that time, and the minimum profile of the bubble and the corresponding effects. The cables appear as nearly vertical lines. Comparison of equivalent control

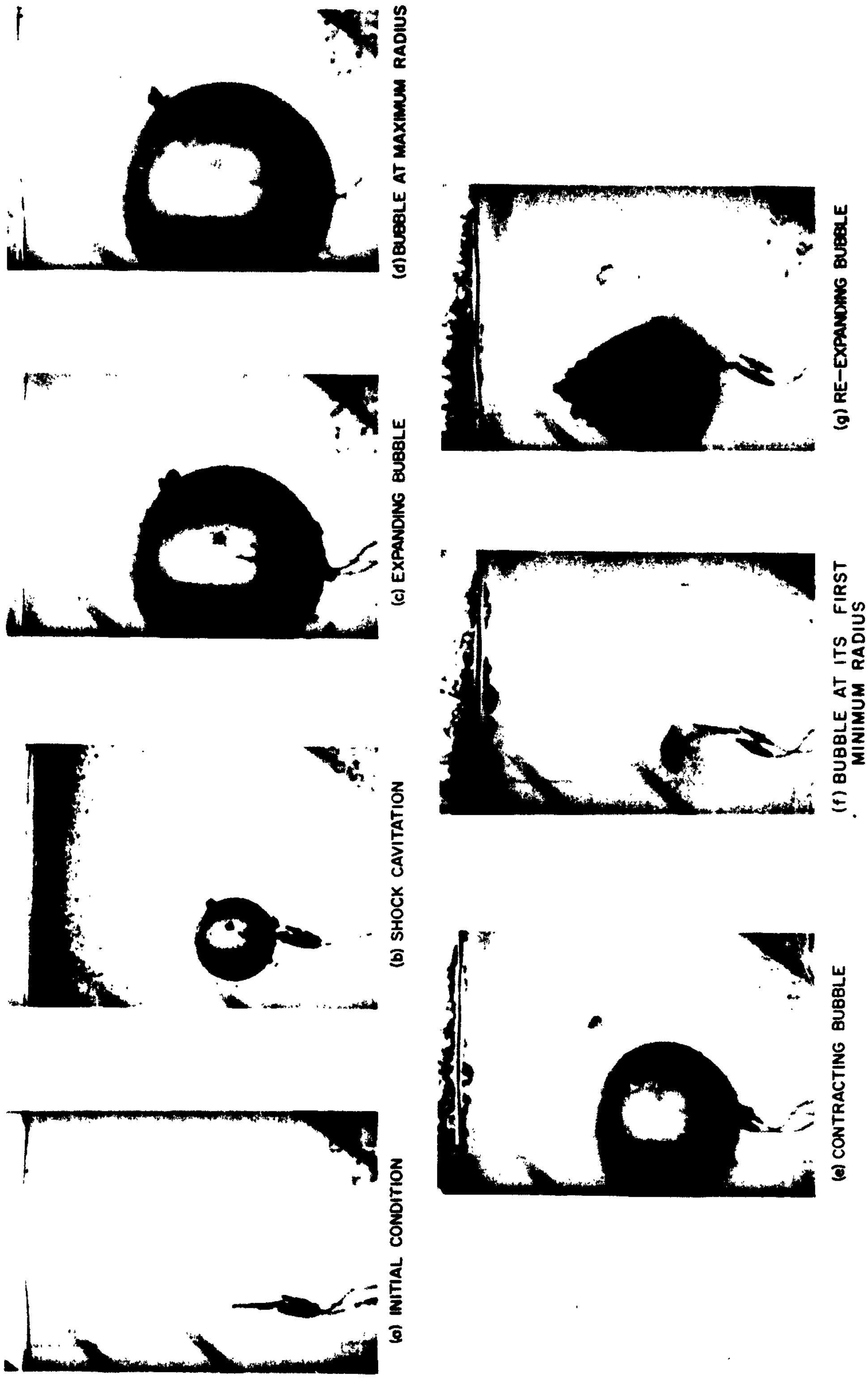
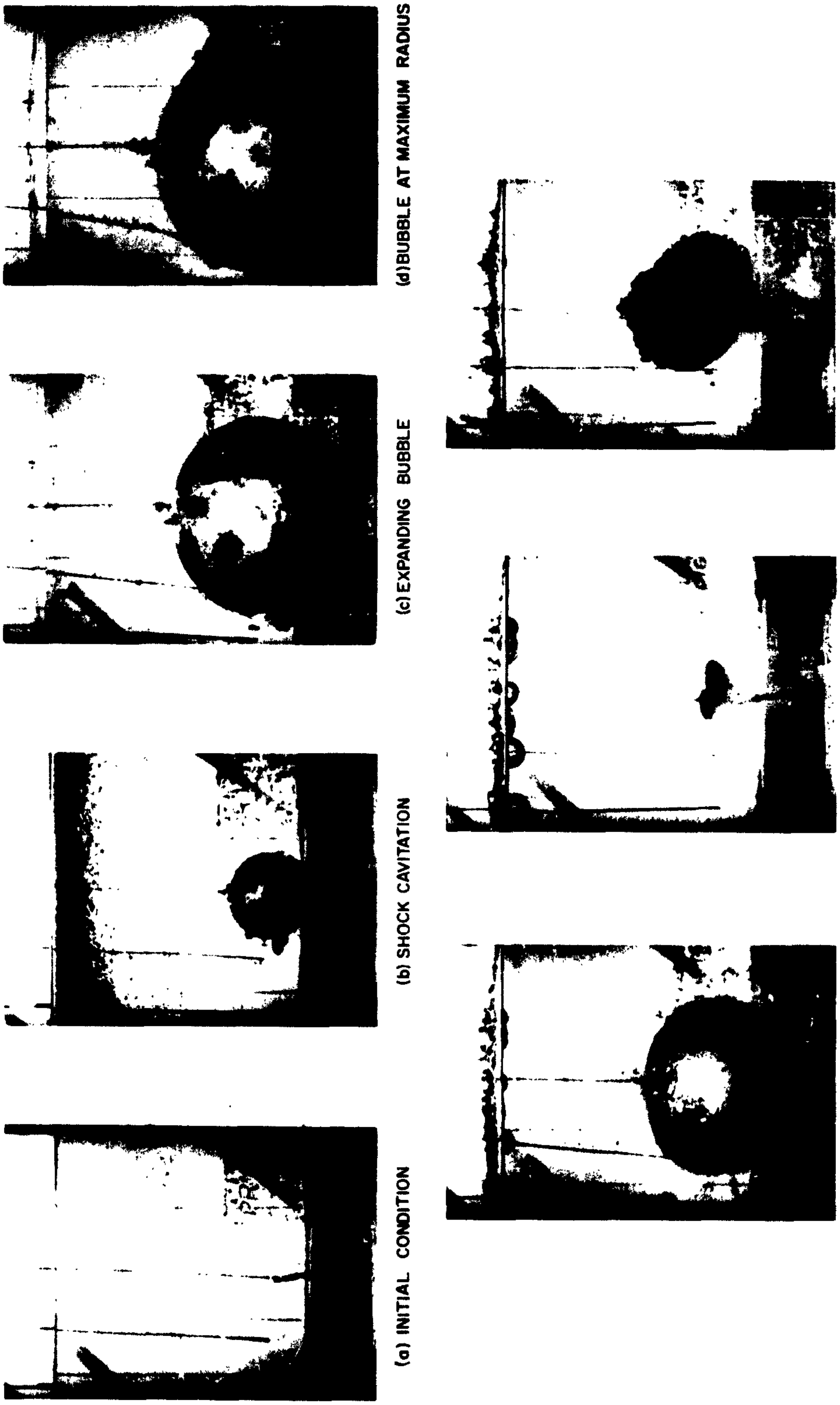


FIG. 7 PICTURES OF SHOT NUMBER PR 1159 ($d/A_{MAX}=2.0$; P=3 FT H_2O; CONTROL)



(a) INITIAL CONDITION

(b) SHOCK CAVITATION

(c) EXPANDING BUBBLE

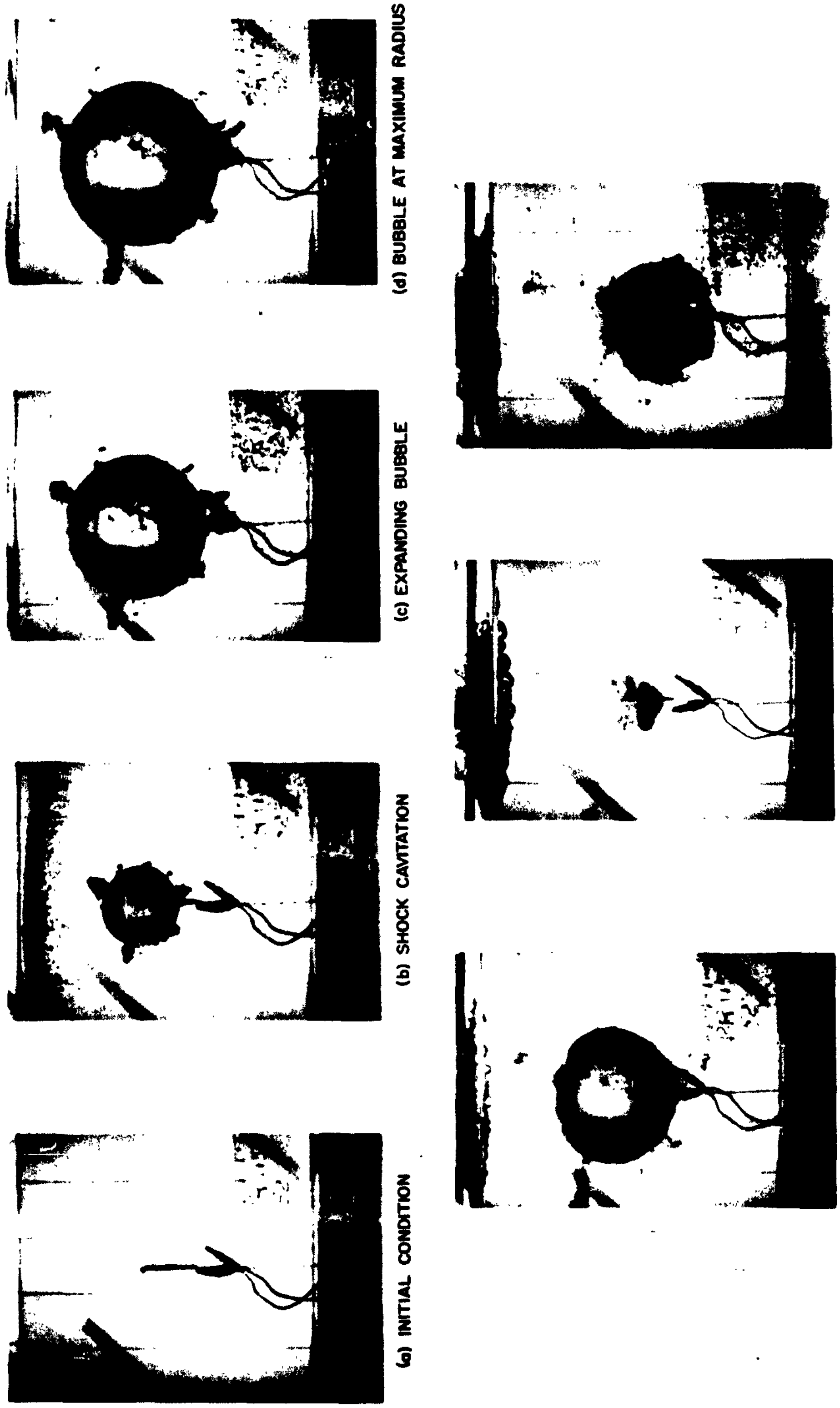
(d) BUBBLE AT MAXIMUM RADIUS

(e) CONTRACTING BUBBLE

(f) BUBBLE AT ITS FIRST MINIMUM RADIUS

(g) RE-EXPANDING BUBBLE

FIG. 8 PICTURES OF SHOT NUMBER PR 1146 ($d/A_{MAX}=2.0$; $P = 3$ FT H_2O)



(a) INITIAL CONDITION

(b) SHOCK CAVITATION

(c) EXPANDING BUBBLE

(d) BUBBLE AT MAXIMUM RADIUS

(e) CONTRACTING BUBBLE

(f) BUBBLE AT ITS FIRST MINIMUM RADIUS

(g) RE-EXPANDING BUBBLE

FIG.9 PICTURES OF SHOT NUMBER PR 1152 (d/A_{MAX} = 1.5; P=10 FT H_2O; CONTROL)

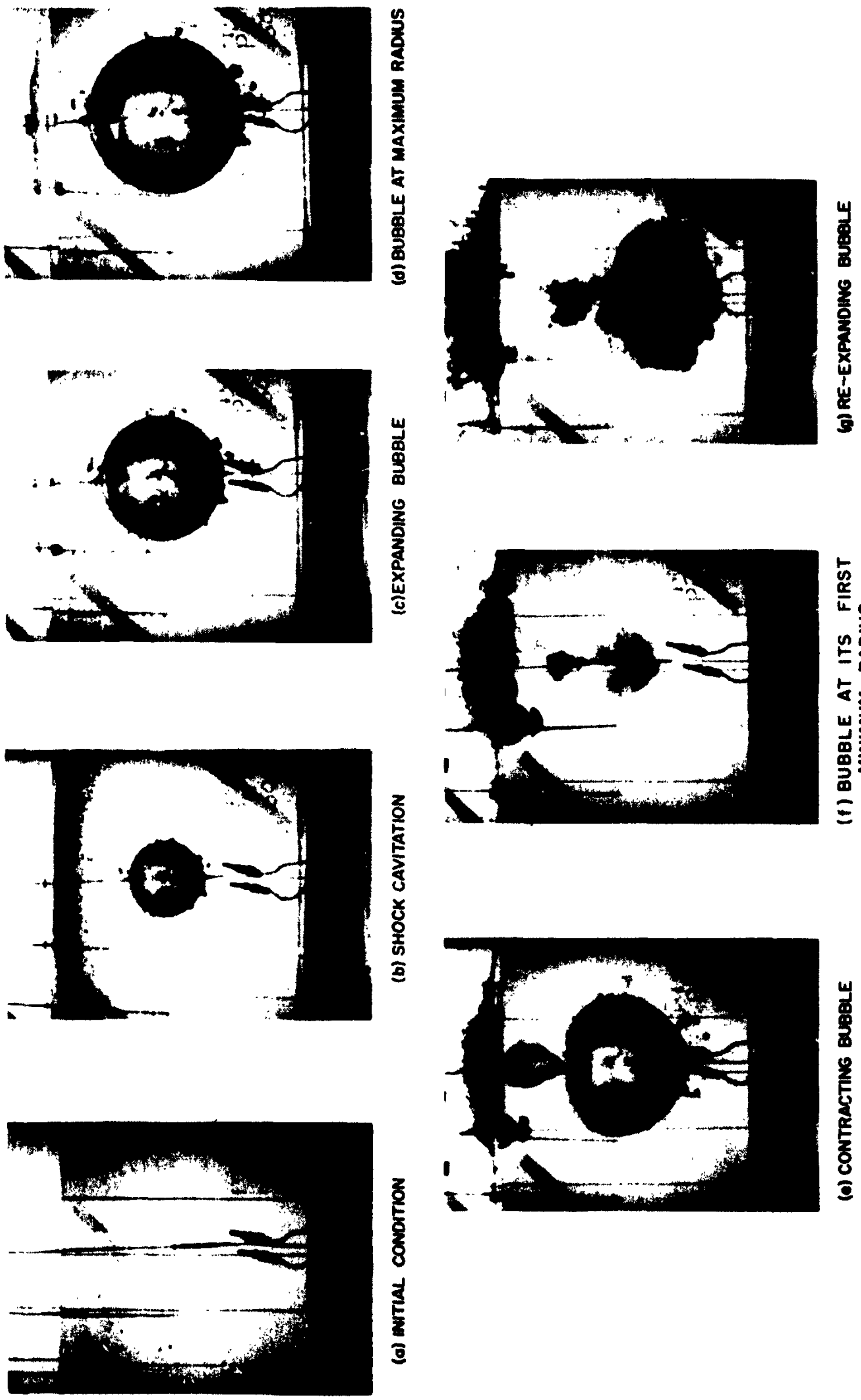
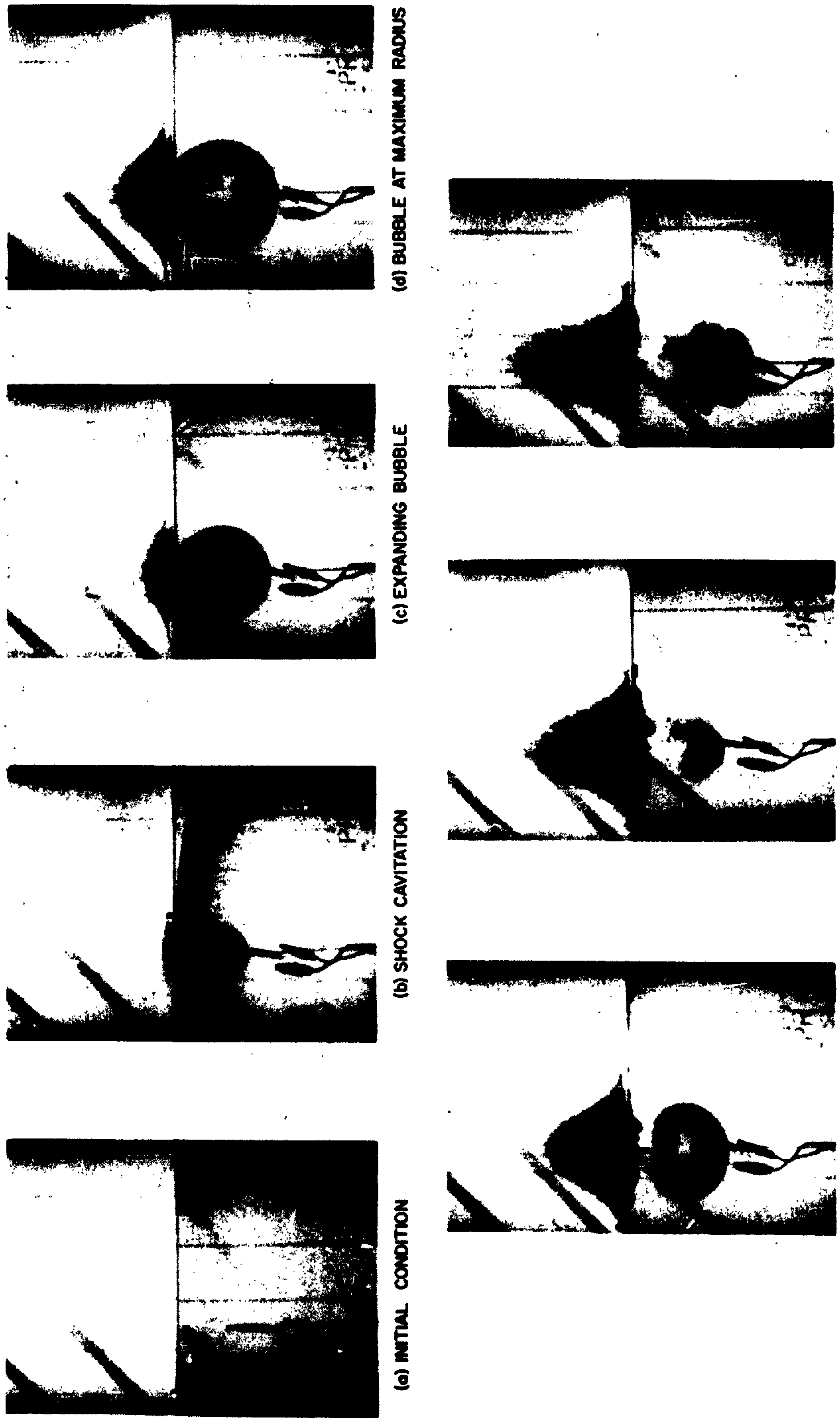


FIG. 10 PICTURES OF SHOT NUMBER PR 1150 (d/A_{MAX} = 1.5; P = 10 FT H_2O)



(a) INITIAL CONDITION

(b) SHOCK CAVITATION

(c) EXPANDING BUBBLE

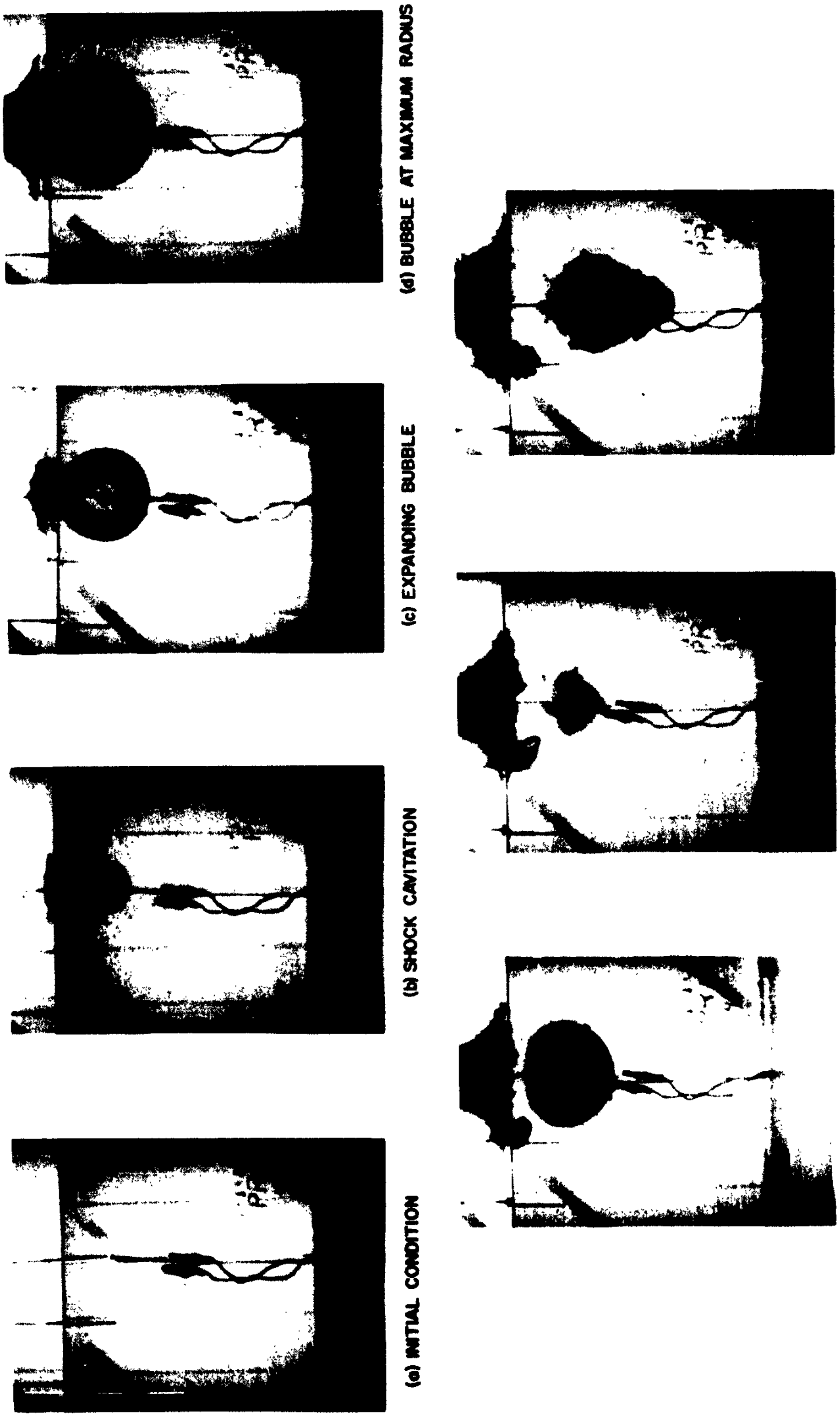
(d) BUBBLE AT MAXIMUM RADIUS

(e) CONTRACTING BUBBLE

(f) BUBBLE AT ITS FIRST MINIMUM RADIUS

(g) RE-EXPANDING BUBBLE

FIG.11 PICTURES OF SHOT NUMBER PR 1158(d/A_{MAX}=1.0; P=34 FT H_2O; CONTROL)



(a) INITIAL CONDITION

(b) SHOCK CAVITATION

(c) EXPANDING BUBBLE

(d) BUBBLE AT MAXIMUM RADIUS

(e) CONTRACTING BUBBLE

(f) BUBBLE AT ITS FIRST MINIMUM RADIUS

(g) RE-EXPANDING BUBBLE

FIG.12 PICTURES OF SHOT NUMBER PR 1148 (d/A_{MAX} =1.0; P=34 FT H_2O)

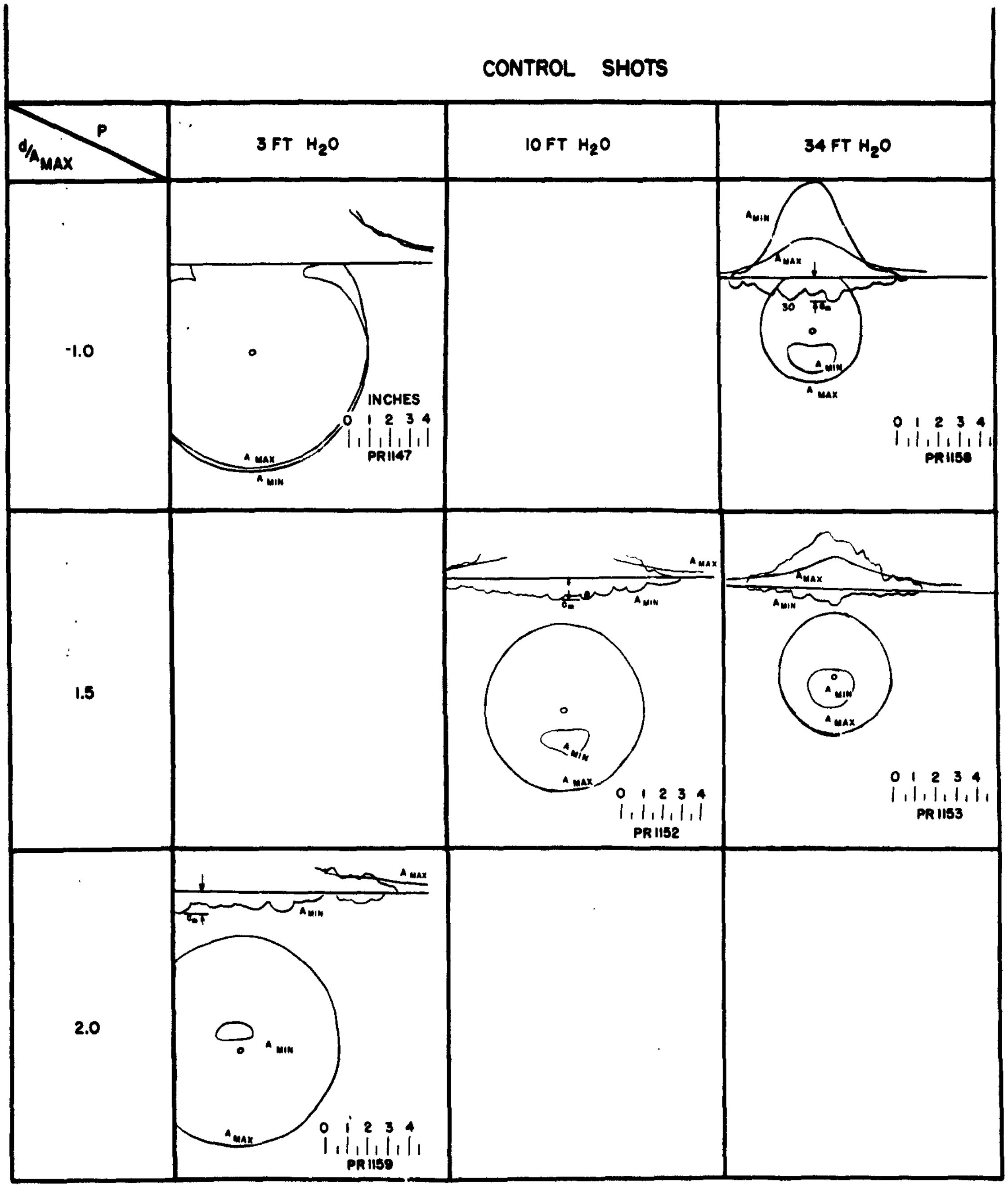


FIG. 13A EXPLOSION BUBBLE AND SURFACE PROFILES

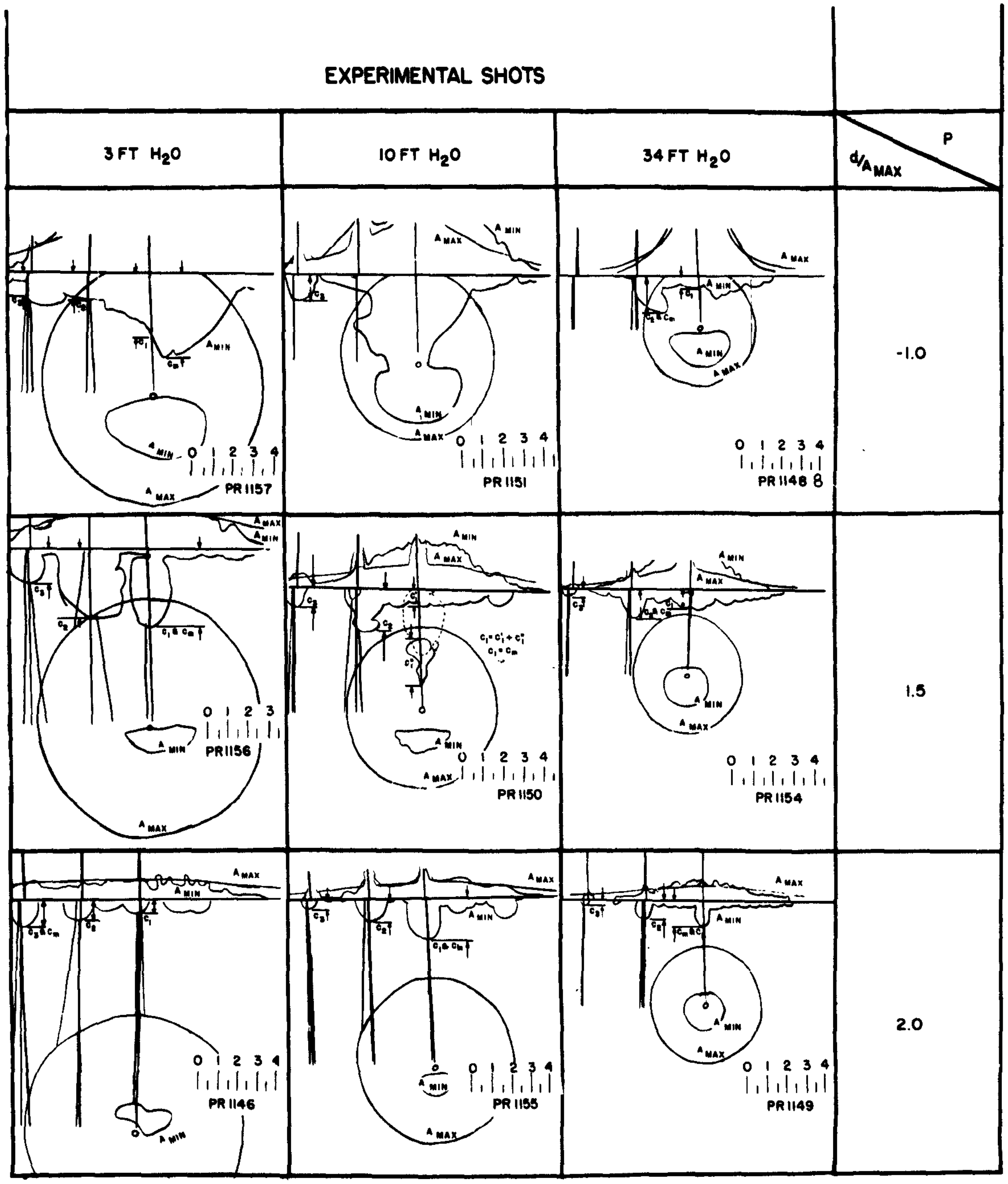


FIG. 13B EXPLOSION BUBBLE AND SURFACE PROFILES

TABLE 2

PROGRAM OF EXPERIMENT

Shot Number	Air Pressure, P (ft. H_2O)	Charge Depth, d (ft)	Scaled Depth d/A_{max}
		EXPERIMENTAL SHOTS	
PR 1157	3	.48	1.0
1156	3	.69	1.5
1146	3	.90	2.0
1151	10	.33	1.0
1150	10	.50	1.5
1155	10	.65	2.0
1148	34	.22	1.0
1154	34	.33	1.5
1149	34	.43	2.0
		CONTROL SHOTS	
1147	3	.48	1.0
1159	3	.90	2.0
1152	10	.50	1.5
1158	34	.22	1.0
1153	34	.33	1.5
		SPECIAL SHOT*	
1160	10	.50	1.5

*A low angle camera shot to view the underside of the surface during the explosion. No measurements were made on the photographs of this shot. (See Figure 15.)

and experimental shots show the effects of the cables. (Three of these comparisons can also be made from Figures 7 through 12.) Comparisons down any column of the experimental shot profiles indicate the effect of scaled depth. Comparisons between rows indicate the effect of air pressure.

In the control shots, many air tubes can be observed extending downward under the water mound when the bubble is at its first minimum. In the experimental shots the tubes generally travelled further downward about the cables. It is apparent that the cables did not cause the air tubes but merely enhanced their development.

In Table 3, values of C_m/A_{max} are given for all of the shots. Penetration is generally greater at shallow scaled charge depths. In two of the shallow scaled shots (one with cables and one without) the air tube is in contact with the explosion bubble at its minimum. When the scaled depth is increased to 2.0, the penetrations are smaller.

TABLE 3. SCALED MAXIMUM TUBE PENETRATIONS, C_m/A_{max}

Scaled Depth d/A_{max}	P = 3 (ft H_2O)	P = 10 (ft H_2O)	P = 34 (ft H_2O)
	CONTROL SHOTS		
1.0	*	--	.43
1.5	--	.26	.29
2.0	.21	--	--
	EXPERIMENTAL SHOTS		
1.0	.72	*	.63
1.5	.67	.80	.50
2.0	.24	.50	.45

*No measurement; tube connected to bubble.

Measurements of scaled maximum air tube penetration along each cable at the time of the bubble minimum, C_i/A_{max}, and the corresponding scaled distance of the cables from the centerline of the explosion, S_i/A_{max}, are shown in Table 4. These data are plotted in Figure 14. A curve is drawn through the data by averaging clusters of data points. There appears to be little change in average penetration out to about 1.2 bubble radii, then penetration decreases. The spread or scatter for tube penetration at cables close to the center line is very large but appears to diminish for greater distances.

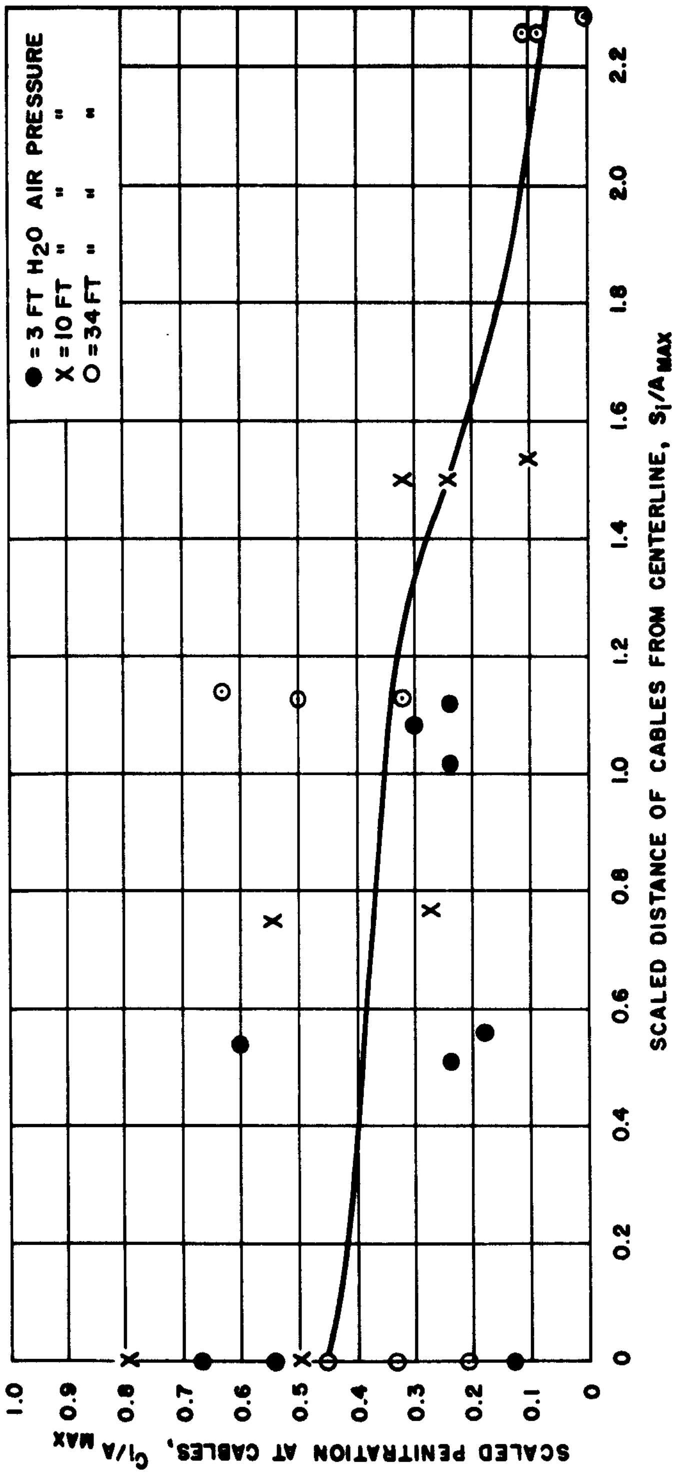


FIG 14 SCALED PENETRATION AT CABLES VS SCALED DISTANCES OF CABLES FROM CENTERLINE OF EXPLOSION

TABLE 4. SCALED TUBE PENETRATION ALONG CABLES, C_i/A_{max}

Air Pressure, P		3 ft H_2O			10 ft H_2O			34 ft H_2O		
d/A_{max}	Cable No., i	1	2	3	1	2	3	1	2	3
1.0	S_i/A_{max}	0	.51	1.02	0	.75	1.50	0	1.14	2.29
	C_i/A_{max}	.54	.24	.24	*	*	.32	.21	.63	0
1.5	S_i/A_{max}	0	.54	1.09	0	.75	1.50	0	1.13	2.26
	C_i/A_{max}	.67	.60	.30	.80	.55	.25	.33	.50	.11
2.0	S_i/A_{max}	0	.56	1.12	0	.77	1.54	0	1.13	2.26
	C_i/A_{max}	.13	.18	.24	.50	.28	.11	.45	.32	.09

*No measurement; tubes connected to bubble.

The effect of air pressure on tube penetration (see Tables 3 and 4 or Figure 14) is somewhat erratic; there is no consistent pattern to indicate that increasing or decreasing air pressure causes predictable changes in air tube penetration. It is therefore concluded that air pressure has little or no effect.

In the vacuum tank, as it is normally used, one part of the phenomena of interest is hidden from view. This is the early growth of the tubes occurring under the water dome. It is only at later times when the tubes extend beneath the initial level of the water surface that they may be observed. One shot was added to the experimental program to photograph the underside of the water-air surface to observe the tube growth at these early times. These pictures are shown in Figure 15; the conditions are listed in Table 2.

The early tube and jet development has been observed by another method. In this study a charge was placed against a transparent rigid boundary and the explosion processes viewed through it. The explosion developed as a symmetrical half of an explosion and when viewed through the boundary can be observed in cross-section. Since the forward part of the water dome which normally blocks observation is eliminated, the phenomena occurring within the dome can be seen. Figure 16 shows selected photographs of such a rigid

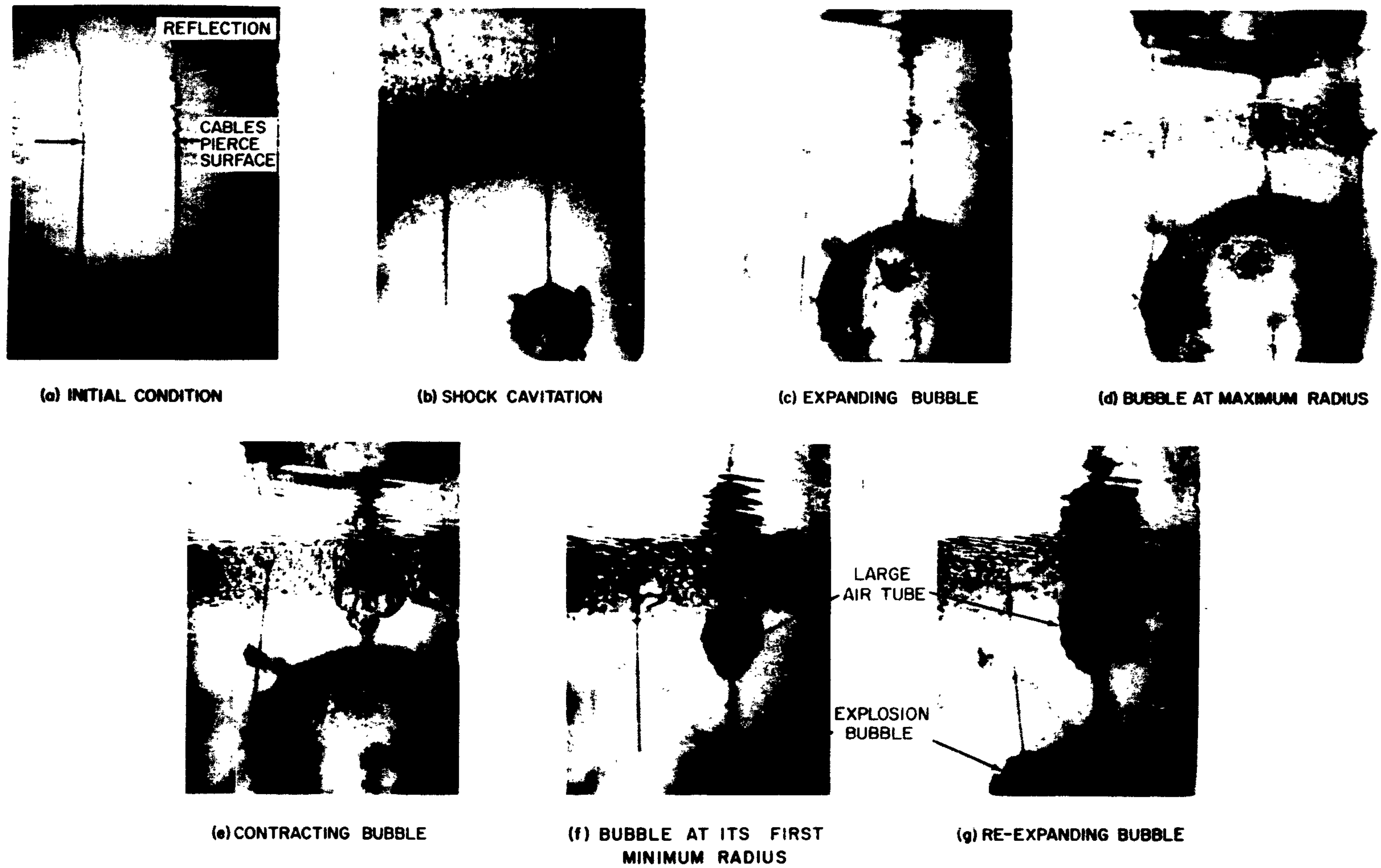


FIG. 15 PICTURES OF SHOT NUMBER PR 1160 (CAMERA BELOW PLANE OF SURFACE)

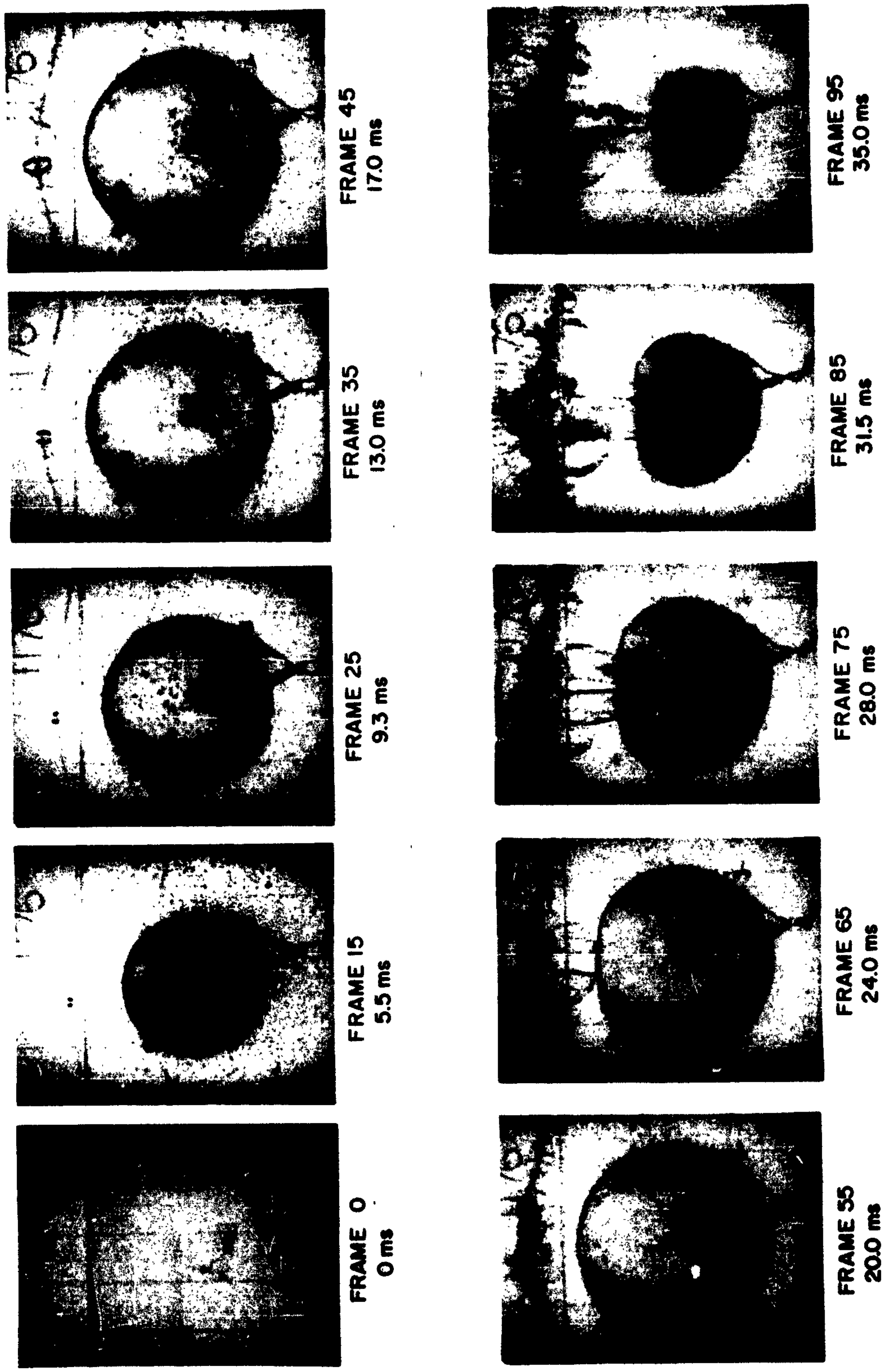


FIG. 16 PICTURES OF RIGID BOUNDARY SHOT PR 1176

boundary shot in which the early tube and jet growth is observed. Several tubes and jets are in evidence; one set has been outlined for clarity and to show the growth. Figure 17 shows the vertical displacement history of the water mound, the bottom of the air tube, and the bubble top and bottom.

5. DISCUSSION

5.1 Observed Instabilities. Sir Geoffrey Taylor has shown that when the interface of two fluid media is accelerated toward the more dense medium, any irregularities which had been present at the interface would exhibit exponential growth into the denser medium (Reference(f)). This proposition is referred to as Taylor's Instability Theory. It is analytically expressed in the relationship

$$\frac{\eta}{\eta_o} = \cosh \left(\frac{2\pi(g_1 - g)(\rho_2 - \rho_1) t^2}{\lambda (\rho_2 + \rho_1)} \right)^{1/2}$$

where η_o = amplitude of initial surface disturbance,

η = amplitude of surface disturbance after some time t,

g = acceleration of gravity,

g_1 = acceleration of the interface toward the more dense medium,

ρ_1 = density of less dense medium,

ρ_2 = density of more dense medium,

λ = wave length of initial surface disturbance,

t = time during which the system is under acceleration.

D. J. Lewis conducted an idealized experimental program, in which the interface between two fluids of unequal density was uniformly accelerated, to confirm Taylor's theory (Reference b). He found that instabilities did grow exponentially and approximately in accordance with Taylor's relationship. In addition, he obtained photographs of the instability growth and these closely resemble the tube and jet growth seen in Figure 16.

The three conditions required for instability growth are present in underwater explosions. An interface between fluids of different densities is present. This air-water interface is initially and for a very short time accelerated upward toward the less dense medium. This is indicated by the initially concave

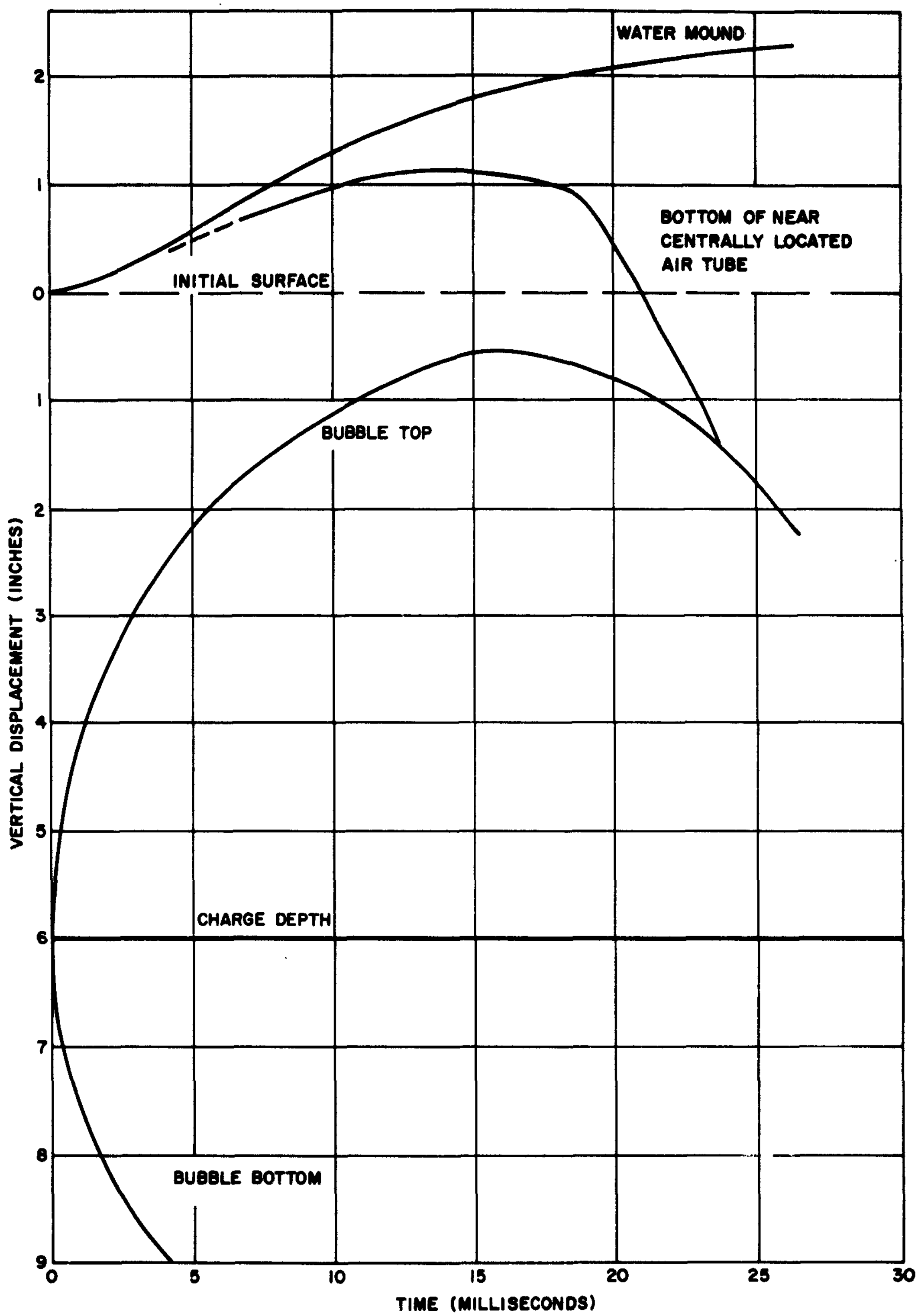


FIG. 17 DISPLACEMENT HISTORY OF RIGID BOUNDARY SHOT PR 1176

upward curvature of the vertical displacement plot for the water mound (or surface) as shown in Figure 17. After two or three milliseconds the surface is decelerating upward or accelerating downward into the more dense medium. At that time, two of the conditions for instability growth are satisfied. The final one is the existence of an initial disturbance at the surface. Although the water surface was not intentionally disturbed prior to any shot, neither was it determined to be perfectly smooth. It may be presumed that surface irregularities caused by the vibration of the vacuum pump, or local flow patterns within the fluid persisting from the filling operation, are present*. Thus, all of the requirements seem to be met. It is therefore concluded that the tubes are instability growths as described by G. I. Taylor. In Figure 17, the air tube motion downward appears to be exponential as expected for such growths. Similarly the jets occurring at the cables grow rapidly at a time when the water surface is decelerating upward. They also appear to be instability growths.

The conclusions reached in Section 4 are consistent with the conditions for Taylor Instabilities:

1. Tubes and jets appear at the cables. The cables act as initial irregularities in the surface and so are points of initiation for instability growths.

2. Air tubes are larger for shallower scaled depths. The nearer the bubble is to the surface, the greater will be the accelerations and subsequent decelerations of the water surface. For deep shots the surface displacements are negligible and instability growth also will be negligible.

3. The magnitude of tube growth is greatest over the bubble and less toward the sides. The velocities and accelerations over the charge are greater than towards the sides, thus larger instability growth will be produced over the bubble, and the smaller accelerations at the sides will produce proportionately smaller instability growth.

4. Air pressure has little or no influence on tube penetration. In Taylor's relationship, only the sum and difference of densities of the two media are involved. The air density, regardless of the air pressure, will be negligible with respect to the water density. Thus air pressure changes should have no measurable effect.

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*In Reference (1) evidence suggests that for impulsive accelerations, as at the explosion surface, surface irregularities may be generated. Thus the surface may initially be smooth and instability growth may still be observed.

5.2 Other Instabilities. The conditions required for instability growth. may also be fulfilled at other times or locations. For example,

1. At the bubble surface near the time of its minimum. Instability may grow on the explosion bubble when it is near its minimum. As the bubble starts its expansion, the surface is accelerating towards the more dense medium. During this phase, tubes might be expected to grow outward from the bubble surface wherever initial irregularities occur. In Figures 7 through 12, at the time of bubble minimum there is an indication that instabilities (tubes) are moving out from the bubble in the direction of migration (upward in Figures 7 and 8, downward in the others).

2. At the water surface when the shock wave is passing through.

6. CONCLUSIONS

Surface jets and underwater air tubes observed in small explosions during the bubble oscillation are believed to develop from initial surface irregularities. Their rapid growth is in accord with Taylor's Instability Theory. Cables penetrating the water surface act as irregularities in the surface and hence can be origins of the air tubes. A circular crest, close to and around each cable, develops into the jets. Although jets and tubes occur elsewhere at the surface, they are usually larger at the location of the cables.

Because these studies were made with tiny explosions and are related to large explosions by simple geometric scaling, any general conclusions reached must be regarded as tentative. However, it seems clear that for moderately deep shots, as encompassed in this experimental study, cables would not provide a path for the release of explosion gases (or radioactive products) into the atmosphere. At the times when the air tubes extend to the bubble it is contracting and atmospheric air flows into the explosion bubble. In nuclear explosions, the turbulence created by atmospheric blow-in may be a factor in the mixing of fission products with the water and, hence, may affect the eventual distribution of the radioactive material.

REFERENCES

(a) Goertner, J. F., "Vacuum Tank Studies of Gravity Migration of Underwater Explosion Bubbles", NAVORD Report 3902, 1 March 1956, Confidential

(b) Lewis, D. L., "The Instability of Liquid Surfaces When Accelerated in a Direction Perpendicular to Their Planes, II", Proceedings of the Royal Society, Volume A202, 1950

(c) Palmer, C. O. J. S., "Phenomena Associated with Small Underwater Explosions - An Investigation by Means of High Speed Photography", Naval Construction Research Establishment, Rosyth, Scotland, Report No. N.C.R.E./R148, November 1950, Restricted

(d) Snay, H. G., Goertner, J. F., and Price, R. S., "Small Scale Experiments to Determine Migration of Explosion Gas Globes Toward Submarines", NAVORD Report 2280, 1 July 1952, Confidential

(e) Swift, E., Fye, P. M. Decius, J. C., and Price, R. S., "Photography of Underwater Explosions, II, High Speed Photographs of Bubble Phenomena", NAVORD Report 95-46, 17 December 1946, Unclassified

(f) Taylor, Sir Geoffrey, "The Instability of Liquid Surfaces When Accelerated in a Direction Perpendicular to Their Planes. I", Proceedings of the Royal Society, Volume A 201, 1950

(g) Zuke, William G., "Laboratory Scaling of Underwater Nuclear Explosion Bubbles" NAVWEPS Report 6707, 21 October 1960, Confidential

(h) Zuke, William G., "Underwater Explosion Scaling Predictions for an Accelerated Test Tank", NAVORD Report 6794, 4 January 1962, Confidential

(i) Allred, J. C. and Blount, G. H., "Experimental Studies of Taylor Instability", LA-1600, November 1953, Unclassified

(j) Slie, W. M. and Derwin, W. D., "Special Detonators for Underwater Explosion Studies", NAVORD Report 3575, 16 November 1953, Confidential

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SUBJECT ANALYSIS OF REPORT

DESCRIPTORS	CODES	DESCRIPTORS	CODES	DESCRIPTORS	CODES
Underwater	UNDE	Water	WATR	Atmospheric	ATMO
Explosion	EXPS	Columns	COLU	Air	AIRE
Bubble	BUBB	Surface	SURA	Tubes	TUBE
Perturbations	PERT	Penetration	PENE	Mixing	MIXE
Boundary	BOUD	Cables	CABL	Radioactive	RADO
High-speed	HIGS	Taylor	TAYO	Products	PROD
Photographs	PHOT	Instability	NONS	Turbulence	TURU
Lead	LEAD	Theory	THEY		
Azide	AZID	Scaling	SCAL		
Explosive	EXPL	Geometry	GEOM		
Charges	CHAR	Nuclear	NUCL		
Depth	DEPT	Flow	FLOW		

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(NAVORD report 6877)
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High speed photographs of underwater explosions of 0.2 gram lead azide charges were made. For depths of 1 to 2 bubble radii, instabilities in the surface led to the formation of surface jets and tubes extending to the bubble. Cables penetrating the surface acted as instabilities. It is tentatively concluded that if this phenomenon occurs in nuclear explosions, the tubes would not provide a path for the escape of fission products, since the flow is inward.

1. Explosions, Underwater
2. Bubbles, Explosion
3. Explosions, Atomic
4. Lead Azides
5. Taylor's instability theory
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II. Zuke, William G.
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